US009421755B2

(12) **United States Patent**
Saad et al.

(10) **Patent No.: US 9,421,755 B2**
(45) **Date of Patent: Aug. 23, 2016**

(54) **SCREEN PRINTING SYSTEM WITH POSITIONAL ALIGNMENT**

(71) Applicants: **Muhammad Redzuan bin Saad**, Selangor (MY); **Zulkifli bin Ambak**, Selangor (MY); **Mohd Zulfadli bin Mohamed Yusoff**, Selangor (MY); **Sabrina Binti Mohd Shapee**, Selangor (MY); **Rosidah bt Alias**, Selangor (MY); **Azmi bin Ibrahim**, Selangor (MY)

(72) Inventors: **Muhammad Redzuan bin Saad**, Selangor (MY); **Zulkifli bin Ambak**, Selangor (MY); **Mohd Zulfadli bin Mohamed Yusoff**, Selangor (MY); **Sabrina Binti Mohd Shapee**, Selangor (MY); **Rosidah bt Alias**, Selangor (MY); **Azmi bin Ibrahim**, Selangor (MY)

(73) Assignee: **TELEKOM MALAYSIA BERHAD**, Kuala Lumpur (MY)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 233 days.

(21) Appl. No.: **14/210,964**

(22) Filed: **Mar. 14, 2014**

(65) **Prior Publication Data**

US 2014/0261027 A1 Sep. 18, 2014

(51) **Int. Cl.**
B41F 15/08 (2006.01)
B41F 15/14 (2006.01)

(52) **U.S. Cl.**
CPC ***B41F 15/0818*** (2013.01); *B41P 2215/11* (2013.01); *B41P 2215/114* (2013.01)

(58) **Field of Classification Search**
CPC B41F 15/08; B41F 15/0813; B41F 33/14
USPC 101/126
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,131,511 A * 10/2000 Wachi B41F 15/10 101/126
8,166,875 B2 * 5/2012 Inoue B41F 15/0818 101/126

FOREIGN PATENT DOCUMENTS

JP 2003159778 A * 6/2003

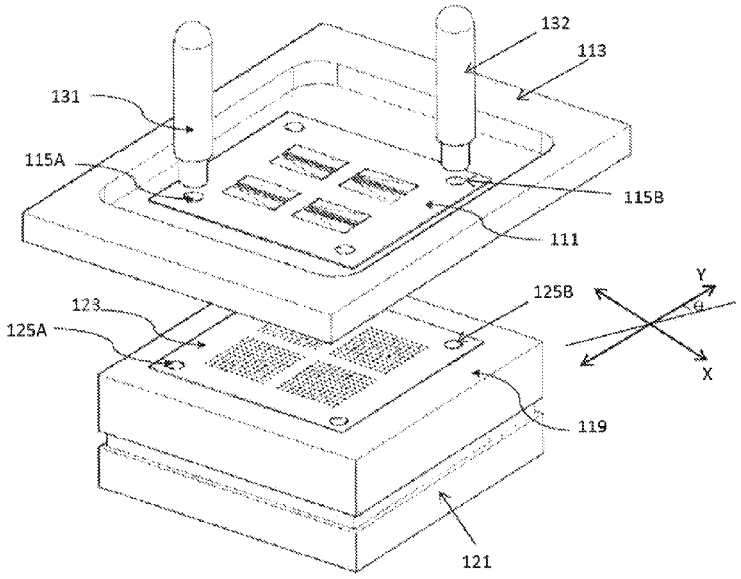
* cited by examiner

Primary Examiner — Leslie J Evanisko
(74) *Attorney, Agent, or Firm* — Moore & Van Allen PLLC; Henry B. Ward, III

(57) **ABSTRACT**

A screen printing system with positional alignment for aligning a substrate with a screen mask. The substrate and the screen mask have two registration holes for facilitating the positional alignment. The positional alignment method includes calculating alignment values for correcting the position of the substrate based on the determined offsets between the registration holes of the substrate and the screen mask. The position of the substrate is corrected based on the calculated alignment values so that registration holes of the substrate are vertically aligned with the registration holes of the screen mask.

32 Claims, 6 Drawing Sheets



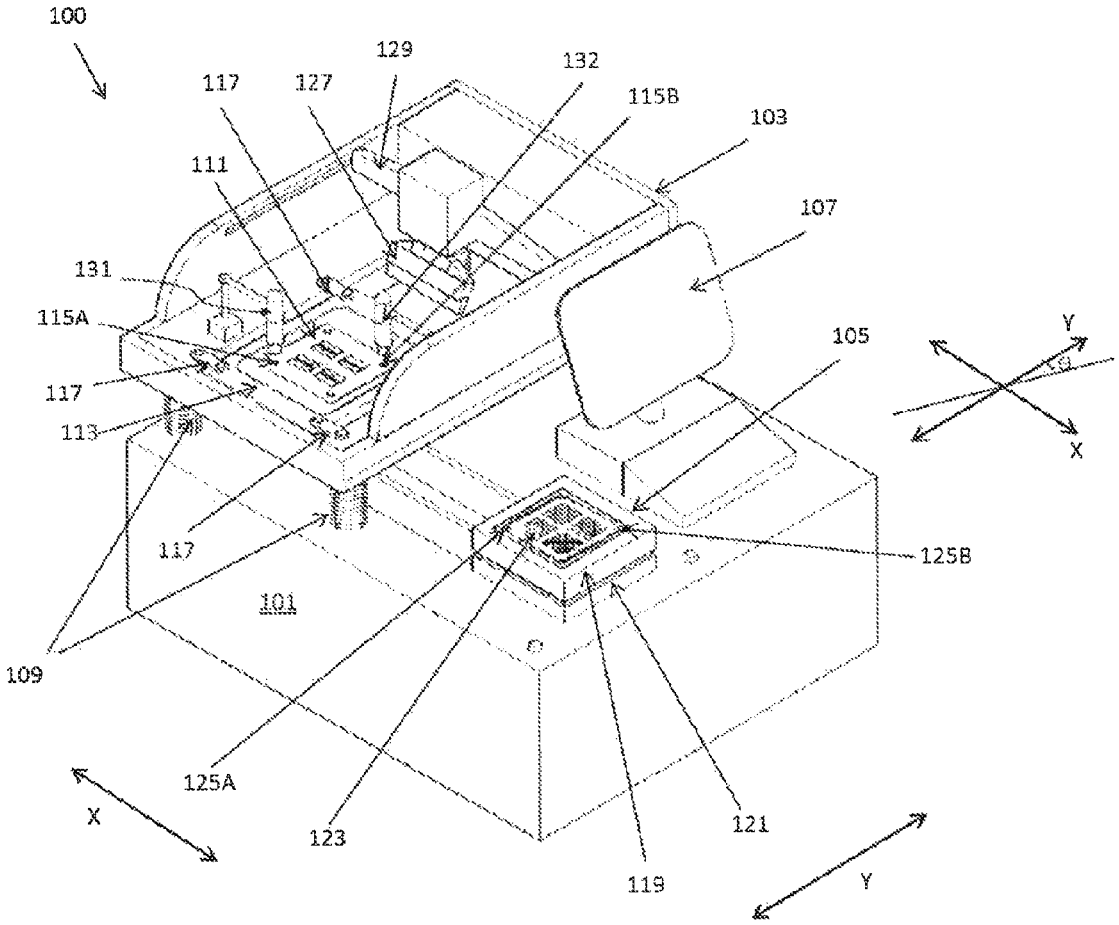

100
129
132
117
127
115B
103
111
107
131
115A
105
Y
117
113
X
117
125B
101
109
125A
X
123
121
119
Y

Fig. 1

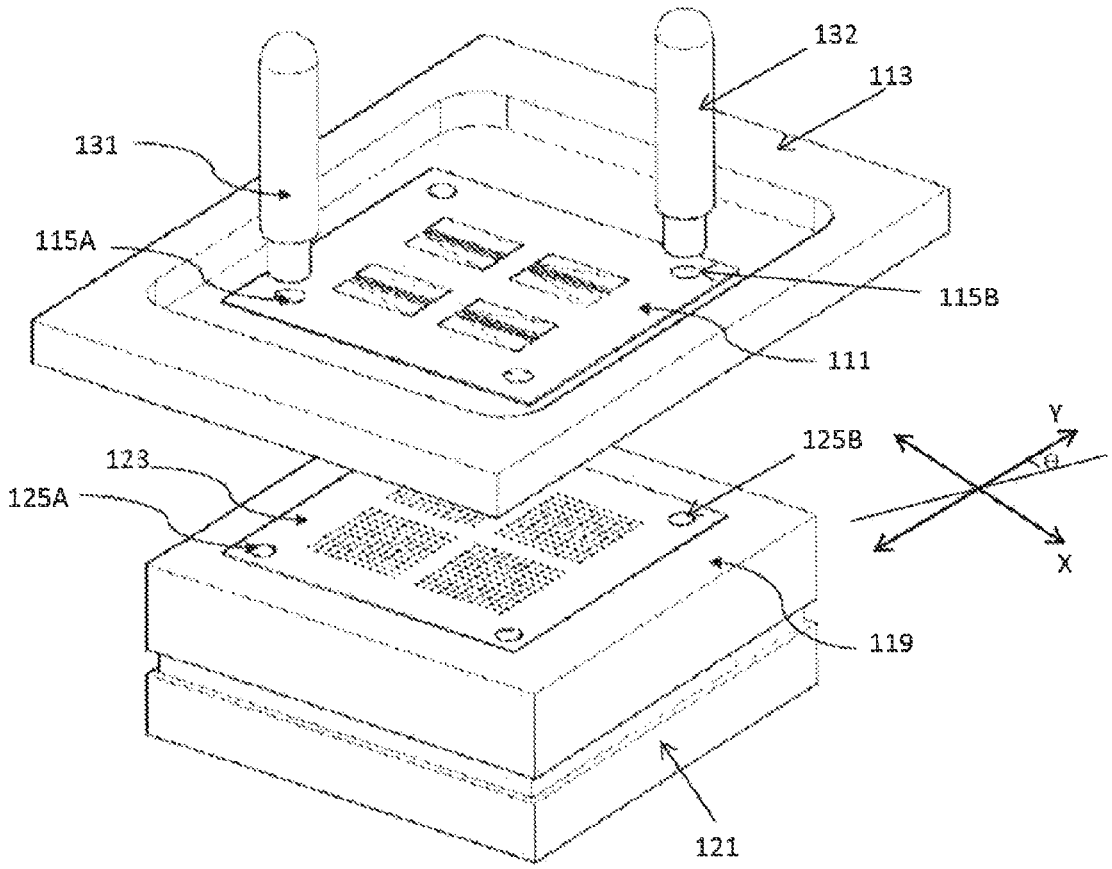


Fig. 2

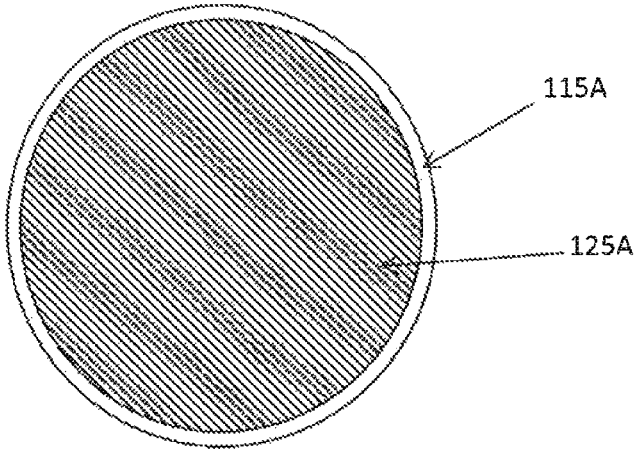


Fig. 3A

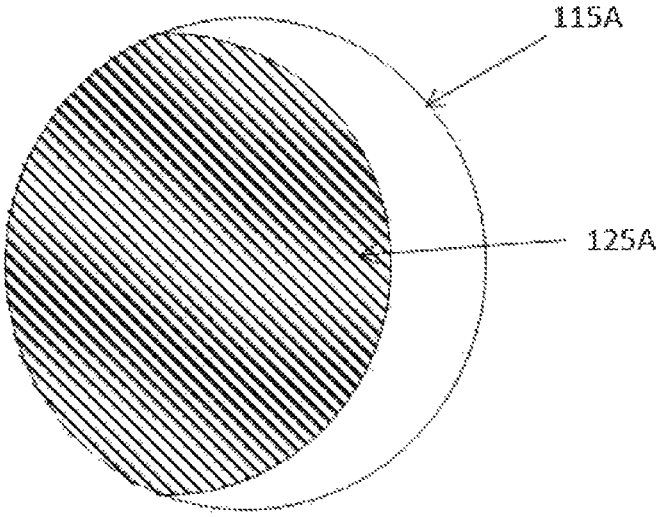


Fig. 3B

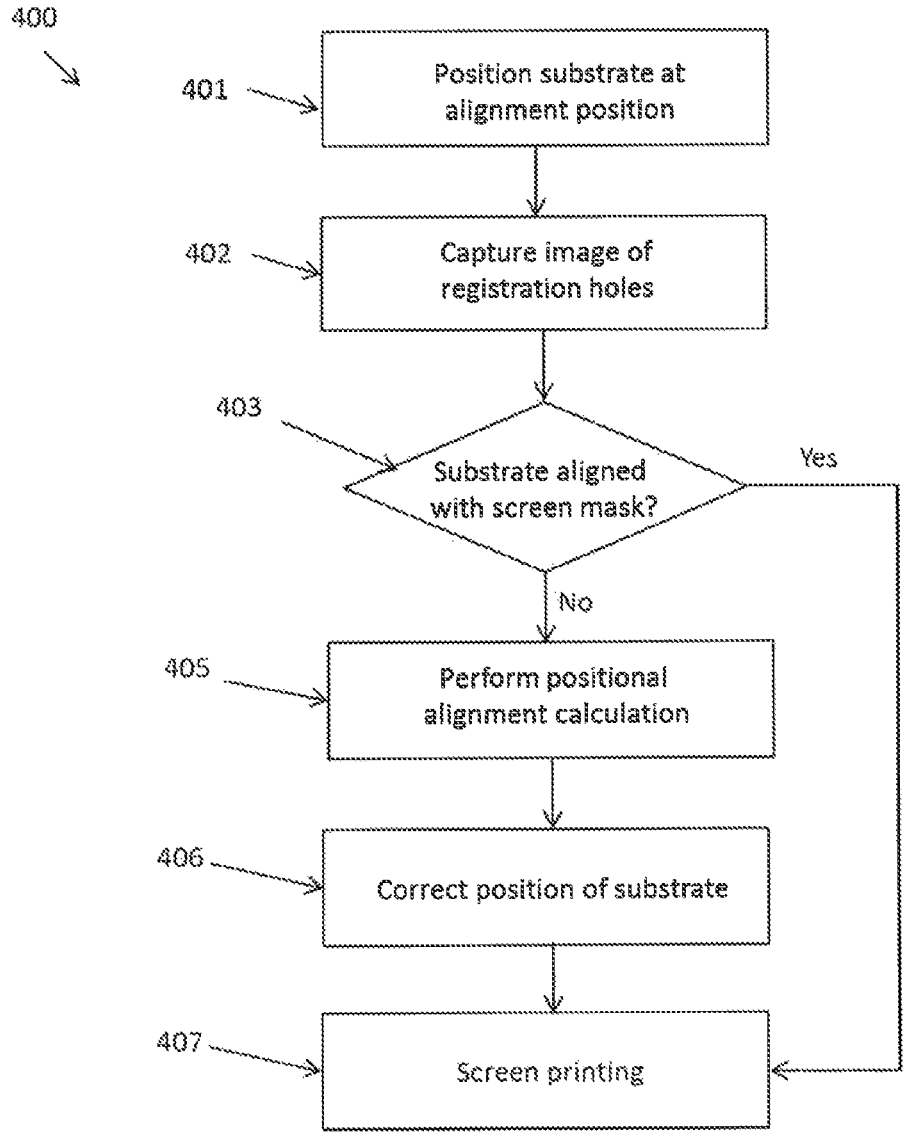

400
401
Position substrate at alignment position
402
Capture image of registration holes
403
Substrate aligned with screen mask?
Yes
No
405
Perform positional alignment calculation
406
Correct position of substrate
407
Screen printing

Fig. 4

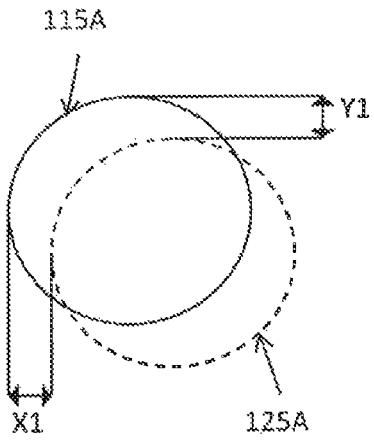


Fig. 5A

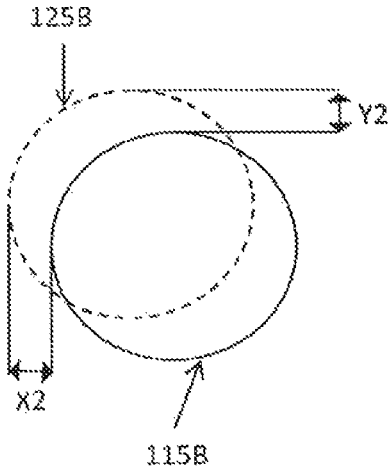


Fig. 5B

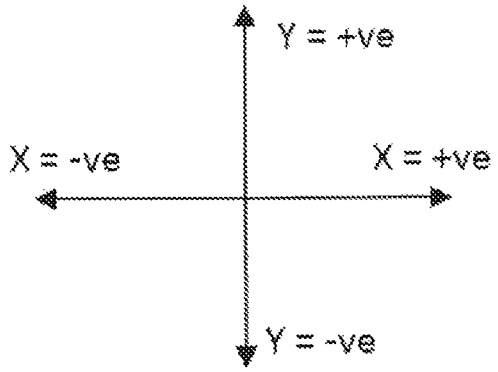


Fig. 5C

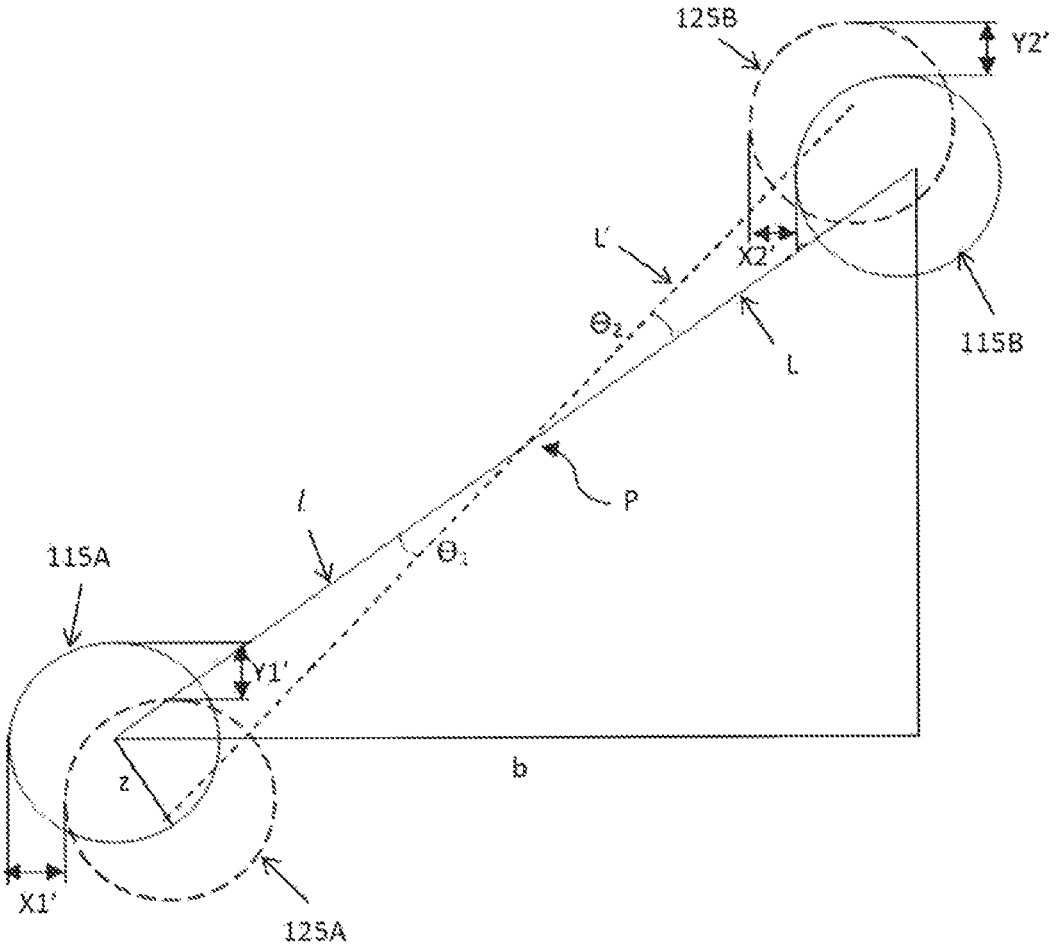


Fig. 6

SCREEN PRINTING SYSTEM WITH POSITIONAL ALIGNMENT

FIELD OF THE INVENTION

This invention relates to a screen printing system with positional alignment. More particularly, this invention relates a method for aligning substrate with screen mask in a screen printing system.

BACKGROUND OF THE INVENTION

Screen printing apparatuses are known for applying a material (e.g. a conductive paste) on the surface of a substrate (e.g. a print tape) to form a particular printing pattern defined by a screen mask or mesh. Typically, a squeegee is pulled across the top surface of a screen mask and pushes the material applied on the screen mask passes through the pattern holes of the screen mask onto the surface of a substrate positioned below the screen mask. It is a known problem that each time a new substrate is positioned at the printing position or a new screen mask is installed in the printing apparatus, the substrate and the screen mask may not in a perfect alignment and thus resulted in an imprecise printing pattern on the substrate. Therefore, if a high printing accuracy is desired, the position of the substrate or the screen mask has to be corrected before the printing process so that the substrate and the screen mask are aligned with each other.

Many alignment methods have been introduced to improve the printing accuracy and throughput. For example, some recognisable markings are printed on the substrate or the screen mask for facilitating the alignment process. The locations of the markings are measured and compared with an expected location so that positional error can be determined and corrected. Many alignment methods are meant for large scale printing systems and hence their methods are complicated and costly to implement. Although there are simpler alignment methods which can be performed semi-auto or manually, these methods are mostly less accurate and hence not desirable.

Therefore, those skilled in art are constantly striving to devise an alignment method for a screen printing system which is simple and able to provide a high printing accuracy.

SUMMARY OF THE INVENTION

The above other problems are solved and an advance in the art is made by a screen printing system that provides an efficient and accurate method for aligning the substrate with the screen mask. The alignment or compensation values for correcting the position of the substrate are determined based on the offsets between the substrate and the screen mask.

A first advantage of the alignment method in accordance with this invention is that the method reduces the setup time and the alignment time of screen mask/substrate, thereby improving the efficiency and productivity of screen printing. This is because the screen printing system and the alignment method of this invention are relative simple and easy to implement with minimum cost. A second advantage of the alignment method in accordance with this invention is that the method enhances the printing accuracy and quality. This is because the alignment method of this invention has less operational errors since it involves simple mathematical calculations. As a precise alignment of the substrate and the screen mask can be achieved with the method in accordance with this invention, some known problems such as short circuit of the conductive lines printed on the substrate can be avoided.

In accordance with a first aspect of this invention, a method for aligning substrate with screen mask in a screen printing system is provided in the following manner. The method comprises: providing a screen mask which has first and second registration holes through the screen mask; positioning a substrate below and substantially parallel to the screen mask wherein the substrate has first and second registration holes through the substrate; capturing a first image of the first registration holes of the screen mask and the substrate with a first image capturing device wherein the first image shows the first registration hole of the screen mask superimposed with the first registration hole of the substrate; capturing a second image of the second registration holes of the screen mask and the substrate with a second image capturing device wherein the second image shows the second registration hole of the screen mask superimposed with the second registration hole of the substrate; determining from the first and second images whether the first and second registration holes of the substrate are vertically aligned with the first and second registration holes of the screen mask; calculating offsets between the first registration holes from the first image and offsets between the second registration holes from the second image in response to a determination that at least one of the registration holes of the substrate is not vertically aligned with the respective registration hole of the screen mask; calculating alignment values for correcting position of the substrate based on the calculated offsets; and correcting position of the substrate based on the calculated alignment values so that the substrate is vertically aligned with the screen mask.

In accordance with embodiments of this invention, the step of calculating the offsets comprises: measuring differences in distance between the first registration hole of the screen mask and the first registration hole of the substrate in a X axis and a Y axis orthogonal to the X axis wherein the X and Y axes define a horizontal X-Y plane parallel to the screen mask and the substrate; and measuring differences in distance between the second registration hole of the screen mask and the second registration hole of the substrate in the X axis and the Y axis.

In accordance with embodiments of this invention, the step of calculating the alignment values comprises modifying the calculated offsets so that the differences in the X axis and the Y axis between the first registration hole of the screen mask and the first registration hole of the substrate are same as the differences in the X axis and the axis between the second registration hole of the screen mask and the second registration hole of the substrate respectively.

In accordance with embodiments of this invention, the step of modifying the calculated offsets comprises: calculating a X_alignment value by this equation: $(X1+X2)/2$ wherein X**1** is the measured difference in the X axis between the first registration holes of the screen mask and the substrate and X**2** is the measured difference in the X axis between the second registration holes of the screen mask and the substrate; and calculating a Y_alignment value by this equation: $(Y1+Y2)/2$ wherein Y**1** is the measured difference in the Y axis between the first registration holes of the screen mask and the substrate and Y**2** is the measured difference in the Y axis between the second registration holes of the screen mask and the substrate.

In accordance with embodiments of this invention, the step of calculating the alignment values further comprises calculating a relative angle between two intersecting line

segments (L, L') based on the X_alignment value, the Y_alignment value and the calculated offsets wherein a first one of the intersecting line segments is linearly connecting the first and second registration holes of the screen mask and a second one of the intersecting line segments is linearly connecting the first and second registration holes of the substrate. The relative angle is calculated using a trigonometry formula.

In accordance with embodiments of this invention, the step of correcting position of the substrate comprises moving the substrate laterally along the X axis by the X_alignment value; moving the substrate laterally along the Y axis by the Y_alignment value; rotating the substrate by the relative angle around an axis perpendicular to the X-Y plane wherein the perpendicular axis is at an intersecting point of the two intersecting line segments (L, L'). The intersecting point is a middle point between the first and second registration holes of the screen mask and a middle point between the first and second registration holes of the substrate.

In accordance with embodiments of this invention, the first and second registration holes of the screen mask are being formed at opposite diagonal corner regions of the screen mask. The first and second registration holes of the substrate are being formed at opposite diagonal corner regions of the substrate. In accordance with an embodiment of this invention, the substrate is a low temperature co-fired ceramic tape.

In accordance with a second aspect of this invention, a system for screen printing with alignment of substrate with screen mask is provided in the following manner. The system comprises: a screen mask holder for holding a screen mask wherein the screen mask has first and second registration holes through the screen mask; a substrate holder for receiving a substrate wherein the substrate has first and second registration holes through the substrate; first and second image capturing devices; an alignment system has a processing unit and a memory readable by the processing unit; and instructions stored by the memory that direct the processing unit to: position the substrate holder below the screen mask holder so that the substrate being substantially parallel to the screen mask; capture a first image of the first registration holes of the screen mask and the substrate with the first image capturing device wherein the first image showing the first registration hole of the screen mask superimposed with the first registration hole of the substrate; capture a second image of the second registration holes of the screen mask and the substrate with the second image capturing device wherein the second image showing the second registration hole of the screen mask superimposed with the second registration hole of the substrate; determine from the first and second images whether the first and second registration holes of the substrate are vertically aligned with the first and second registration holes of the screen mask respectively; calculate offsets between the first registration holes from the first image and offsets between the second registration holes from the second image in response to a determination that at least one of the registration holes of the substrate is not vertically aligned with the respective registration hole of the screen mask; calculate alignment values for correcting position of the substrate based on the calculated offsets; and correct position of the substrate based on the calculated alignment values so that the substrate is vertically aligned with the screen mask.

In accordance with embodiments of this invention, the substrate holder is movable laterally along a first axis relative to the screen mask. The substrate holder is movable laterally along a second axis orthogonal to the first axis relative to the screen mask. The substrate holder is rotatable around an axis perpendicular to the screen mask. The screen mask holder is movable vertically relative to the substrate holder.

In accordance with embodiments of this invention, the system further comprises a slidable table on which the substrate holder is mountable wherein the slidable table is movable laterally relative to the screen mask holder. The system further comprises an interface unit in communication with the alignment system wherein the interface unit allows a user to view images and/or enter data. For example, the interface unit is a touch screen.

In accordance with embodiments of this invention, the first and second registration holes of the screen mask are being formed at opposite diagonal corner regions of the screen mask. The first and second registration holes of the substrate are being formed at opposite diagonal corner regions of the substrate. The substrate is a low temperature co-fired ceramic tape.

In accordance with embodiments of this invention, the instructions to calculate the offsets comprise: instructions to measure differences in distance between the first registration hole of the screen mask and the first registration hole of the substrate in a X axis and a Y axis orthogonal to the X axis wherein the X and Y axes define a horizontal X-Y plane parallel to the screen mask and the substrate; and instructions to measure differences in distance between the second registration hole of the screen mask and the second registration hole of the substrate in the X axis and the Y axis.

In accordance with embodiments of this invention, the instructions to calculate the alignment values comprise instructions to modify the calculated offsets so that the differences in the X axis and the Y axis between the first registration hole of the screen mask and the first registration hole of the substrate are same as the differences in the X axis and the Y axis between the second registration hole of the screen mask and the second registration hole of the substrate respectively.

In accordance with embodiments of this invention, the instructions to modify the calculated offsets comprise: instructions to calculate a X_alignment value by this equation: $(X1+X2)/2$ wherein X1 is the measured difference in the X axis between the first registration holes of the screen mask and the substrate and X2 is the measured difference in the X axis between the second registration holes of the screen mask and the substrate; and instructions to calculate a Y_alignment value by this equation: $(Y1+Y2)/2$ wherein Y1 is the measured difference in the Y axis between the first registration holes of the screen mask and the substrate and Y2 is the measured difference in the Y axis between the second registration holes of the screen mask and the substrate.

In accordance with embodiments of this invention, the instructions to calculate the alignment values further comprise instructions to calculate a relative angle between two intersecting line segments (L, L') based on the X_alignment value, the Y_alignment value, and the calculated offsets wherein a first one of the intersecting line segments is linearly connecting the first and second registration holes of the screen mask and a second one of the intersecting line segments is linearly connecting the first and second registration holes of the substrate. The relative angle is calculated using a trigonometry formula.

In accordance with embodiments of this invention, the instructions to correct position of the substrate comprise instructions to move the substrate laterally along the X axis by the X_alignment value; instructions to move the substrate

laterally along the Y axis by the Y_alignment value; instructions to rotate the substrate by the relative angle around an axis perpendicular to the X-Y plane wherein the perpendicular axis is at an intersecting point of the two intersecting line segments (L, L'). The intersecting point is a middle point between the first and second registration holes of the screen mask and a middle point between the first and second registration holes of the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other aspects of this invention will now be described, by way of example only, with reference to the accompany drawings, in which:

FIG. **1** is a perspective view of a screen printing system according to an embodiment of the invention;

FIG. **2** is an enlarged view of a screen mask holder and a substrate holder in the screen printing system shown in FIG. **1**;

FIG. **3**A is a plan view of two perfectly aligned registrations holes of the screen mask and the substrate;

FIG. **3**B is a plan view two misaligned registrations holes of the screen mask and the substrate;

FIG. **4** is a flow chart showing an alignment method of the substrate with the screen mask in according to an embodiment of the invention;

FIG. **5**A is a plan view image captured by the first camera showing offsets (X**1**, Y**1**) in the X axis and the Y axis of first registration holes of the screen mask and the substrate;

FIG. **5**B is a plan view image captured by the second camera showing offsets (X**2**, Y**2**) in the X axis and the Y axis of second registration holes of the screen mask and the substrate;

FIG. **5**C showing the offset values are determined by the direction of the measurement.

FIG. **6** is an illustration showing the modified offsets of the registration holes of the screen mask and the substrate.

DETAILED DESCRIPTION OF THE INVENTION

This invention relates to a screen printing system and a method for aligning the substrate with the screen mask. The alignment values for correcting the position of the substrate are based on the offsets between registration holes of the screen mask and the substrate.

FIGS. **1** and **2** show perspective views of a screen printing system **100** in accordance with an embodiment of the invention. Screen printing system **100** has base **101** on which various components are mounted or connected to, including, but not limited to, screen mask station **103**, substrate station **105** and input/output unit **107**. Base **101** could be the housing for certain hardware and software components, for example processing unit and memory unit of an alignment system of screen printing system **100**.

Screen mask station **103** is disposed above base **101** and supported by a plurality of legs **109**. Each leg **109** at one end is connected to screen mask station **103** and at the other end is connected to base **101**. All of the legs **109** are movable vertically and simultaneously relative to base **101** so that the height of screen mask station **103** can be adjusted. Screen mask station **103** comprises screen mask holder **113** for holding a screen mask **111**. Screen mask **111** is a metal plate, preferably in a rectangular shape, having mesh holes defining a printing pattern. Two registration holes **115**A, **115**B are formed through screen mask **111**. Preferably, through holes **115**A, **115**B are formed at the opposite diagonal corners of screen mask **111**. Although two registration holes are described in this application, more holes may be formed in screen mask **111**. Through holes **115**A, **115**B are useful for the alignment process which will be discussed later. Each of the registration holes **115**A, **115**B has a circular shape (viewing from top) with a diameter of approximately 3 mm. Other shapes of registration hole are possible without departing from this invention. Screen mask holder **113** is removably mounted to screen mask station **103** by locking means, such as locking plate **117** as shown in FIG. **1**. Preferably, screen mask holder **113** has a frame-shaped opening in which a screen mask can be attached to. This frame-shaped opening is useful as a screen mask can be installed and replaced easily, without replacing the whole screen mask holder **113**.

Substrate station **105** is mounted on base **101** and comprises two components connected to each other, namely substrate holder **119** and slidable table **121**. Substrate holder **119** for holding a substrate is mounted on top of slidable table **121** so that movement of slidable table **121** causes substrate holder **119** to move together simultaneously. In a preferred embodiment of the invention, a low temperature co-fired ceramic (LTTC) tape is used as a substrate. However, substrate can be any materials which are suitable for screen printing process. Two registration holes **125**A, **125**B are formed through substrate **123**. Preferably, through holes **125**A, **125**B are formed at the opposite diagonal corners of substrate **123**. Although two registration holes **125**A, **125**B are described in this application, more holes may be formed in substrate **123**. Similar to screen mask **111**, each of the registration holes **125**A, **125**B has a circular shape (viewing from top) with a diameter of approximately 3 mm. Other shapes of registration hole are possible without departing from this invention. In this invention, the size of registration holes **125**A, **125**B of substrate **123** is substantially same as the size of registration holes **115**A, **115**B of screen mask **111**.

Slidable table **121** is movable laterally along a X axis (shown by arrow X in FIGS. **1** and **2**) between a loading position and an alignment position. At loading position (see FIG. **1**), substrate station **105** is at an access area away from screen mask station **103** so that substrate **123** can be conveniently loaded onto substrate holder **119**. At alignment position (see FIG. **2**), substrate station **105** is positioned directly below a screen mask held by screen mask holder **113** so that substrate **123** being substantially parallel and adjacent to screen mask **111**. If registration holes **125**A, **125**B of substrate **123** are precisely coincided with registration holes **115**A, **115**B of screen mask **111** respectively, substrate **123** will be perfectly aligned with screen mask **111**. In other words, circular shapes of registration holes **115**A, **115**B of screen mask **111** are perfectly superimposed on the circular shapes of registration holes **125**A, **125**B of substrate **123** respectively (see FIG. **3**A for an example). If this is the case, substrate **123** may proceed directly to screen printing process. However, if any one (or both) of the registration holes **125**A, **1258** of substrate **123** is not precisely coincided with the respective one of the registration holes **115**A, **115**B of screen mask **111**, substrate **123** will be misaligned with screen mask **111**. In other words, at least one of the registration holes **115**A, **1158** of screen mask **111** is not perfectly superimposed on the respective one of the registration holes **125**A, **125**B of substrate **123** (see FIG. **3**B for an example). If this is the case, the position of substrate **123** has to be adjusted to correct the misalignment before the screen printing process.

The position of substrate holder **119** is independently adjustable in different directions for aligning substrate **123**

with screen mask **111**. Substrate holder **119** is movable laterally along a X axis (shown by arrow X in FIGS. **1** and **2**). Substrate holder **119** is also movable laterally along a Y axis (shown by arrow Y in FIGS. **1** and **2**) which is orthogonal to the X axis in the same plane. X and Y axes define a two-dimensional horizontal plane which is referred to as X-Y plane, parallel to screen mask **111** and substrate **123**. Further, substrate holder **119** is rotatable (clockwise or anti-clockwise between X and Y axes) in the X-Y plane around an axis perpendicular to the X-Y plane. In other words, substrate holder **119** is rotatable around an axis perpendicular to screen mask **111**.

In screen printing station **103**, squeegee **127** and a chamber containing a printing material (e.g. conductive paste) are connected to movable plate **129**. Movable plate **129** is mounted to screen mask station **103** and is movable to bring the attached squeegee **127** to slide across the top surface of screen mask **111**. During printing process, a printing material is dispensed on screen mask **111** and squeegee **127** is made to slide on screen mask **111** to apply the printing material across the surface of screen mask **111**. This causes the printing material to pass through the pattern/mesh holes of screen mask **111** onto the printing surface of substrate **123** positioned below screen mask **111**.

Two cameras, **131**, **132** are attached to screen mask station **103** and disposed above registration holes **115**A, **115**B of screen mask **111** respectively. Preferably, cameras **131**, **132** are positioned directly above and adjacent to registration holes **115**A, **115**B respectively so that, at alignment position, an image of two superimposed circulars of registration holes (**115**A superimposed with **125**A; **115**B superimposed with **125**B) of screen mask **111** and substrate **123** can be captured by each camera clearly. These images are useful in positional alignment process in accordance with this invention. Although a camera is described in this application, one skilled in the art will recognise that other image capturing devices can be used.

In accordance with an embodiment of the invention, the position of screen mask **111** is fixed which represents the expected position for printing process. Therefore, the position of substrate **123** has to be aligned with screen mask **111** before a printing process can be carried out. If substrate **123** is aligned with screen mask **111**, the image captured by first camera **131** shows two perfectly superimposed (matched) circulars of registration holes **115**A, **125**A; and the image captured by second camera **132** shows two perfectly superimposed (matched) circulars of registration holes **115**B, **125**B. See FIG. **3**A as an example. If substrate **123** is misaligned with screen mask **111**, the image captured by first camera **131** shows two not perfectly superimposed (mismatched) circulars of registration holes **115**A, **1254**; and/or the image captured by second camera **132** shows two not perfectly superimposed (mismatched) circulars of registration holes **115**B, **125**B. See FIG. **4**B as an example.

A method for aligning substrate **123** with screen mask **111** automatically by calculating alignment values to correct the position of substrate **123** is described in the following manner and illustrated by a flow chart **400** shown in FIG. **4**, in accordance with an embodiment of the invention. A screen mask **111** having two registration holes **115**A, **115**B is installed in screen mask station **103**. In step **401**, a substrate **123** having two registration holes **125**A, **1258** is placed on substrate station **105** and positioned below screen mask **111** at alignment position. Substrate **123** is substantially parallel and adjacent to screen mask **111**. In step **402**, first camera **131** is activated to capture an image of first registration holes of screen mask **111** and substrate **123**. The image captured by first camera **131** shows two superimposed circulars of first registration holes **115**A, **125**A. Second camera **132** is also activated to capture an image of second registration holes of screen mask **111** and substrate **123**. The image captured by second camera **132** shows two superimposed circulars of second registration holes **115**B, **125**B.

In step **403**, the method determines whether substrate **123** is perfectly aligned with screen mask **111** based on the images captured in step **402**. This step is performed by an image processing system. If substrate **123** is perfectly aligned with screen mask **111**, two perfectly superimposed circulars of registrations holes is observed from each captured image (i.e. no offset between two superimposed circulars). See FIG. **3**A for an example. Hence, substrate **123** may proceed directly to screen printing process in step **407**. However, if substrate **123** is misaligned with screen mask **111**, at least one of the captured images showing two not perfectly superimposed circulars of registrations holes (i.e. offsets are observed between two superimposed circulars). See FIG. **3**B for an example. Hence, the position of substrate **123** has to be corrected so that registration holes **125**A, **125**B of substrate **123** are vertically aligned with registration holes **115**A, **115**B of screen mask **111** respectively.

In step **405**, positional alignment calculation is performed and alignment values for compensating offsets between the registration holes of substrate **123** and screen mask **111** are determined. The details of step **405** are described in the following manner with reference to FIGS. **5** and **6**.

Differences in distance (i.e. offsets) between two superimposed circulars of first registration holes (**115**A, **125**A) of screen mask **111** and substrate **123** with respect to X axis and Y axis are determined by an image processing system based on the image captured by first camera **131** in step **402**. These offsets are denoted by 'X**1**' in X axis and 'Y**1** in Y axis as shown in FIG. **5**A. Similarly, offsets between two superimposed circulars of second registration holes (**115**B, **125**B) of screen mask **111** and substrate **123** with respect to X axis and Y axis are determined by an image processing system based on the image captured by second camera **132** in step **402**. These offsets are denoted by 'X**2**' in X axis and 'Y**2**' in Y axis as shown in FIG. **5**B. The offset values may be positive or negative depending on the direction of the measurement as shown in FIG. **5**C. For example, offsets X**1** and X**2** are positive values if they are measured in the X-direction from left to right. Conversely, in the opposite direction, i.e. from right to left, X**1** and X**2** are negative values. Offsets Y**1** and Y**2** are positive values if they are measured in the Y-direction from bottom to top. Conversely, in the opposite direction, i.e. from top to bottom, Y**1** and Y**2** are negative values.

Based on the determined offsets X**1**, Y**1**, X**2** and Y**2**, mean value of X**1** and X**2** (denoted by 'X_alignment') and mean value of Y**1** and Y**2** (denoted by 'Y_alignment') are calculated using the following equations:

$$X\_\text{alignment}=(X1+X2)/2,\ Y\_\text{alignment}=(Y1+Y2)/2$$

Subsequently, offsets X**1**, Y**1**, X**2** and Y**2** are being modified to X**1'**, Y**1'**, X**2'** and Y**2'** respectively using the following equations:

$$X1'=X1-X\_\text{alignment},\ Y1'=Y1-Y\_\text{alignment}$$

$$X2'=X2-X\_\text{alignment},\ Y2'=Y2-Y\_\text{alignment}$$

The purpose of modifying the offset values is to ensure that the offsets in X and Y axes between the first registration holes **115**A, **125**A are same as the offsets in X and Y axes between the second registration holes **115**B, **125**B, i.e. magnitudes of X**1'** and Y**1'** are same as magnitudes of X**2'**

and Y2' respectively. Therefore, if X1'=X2' and Y1'=Y2', the line L connecting the first and second registration holes **115**A, **115**B of screen mask **111** and line L' connecting the first and second registration holes **125**A, **125**B of substrate **123** will intersect at an intersecting point P (see FIG. **6**) which is the middle point of line L and line L'. As a result of the offset modification, line L is deviated from line L' by a relative angle θ in X-Y plane, and θ=θ1=θ2 as shown in FIG. **6**. A rotation of the substrate around point P in X-Y plane by an angle θ will result in line L coincides with line L', in which first and second registration holes **125**A, **125**B of substrate **123** are perfectly aligned with first and second registration holes **115**A, **115**B of screen mask **111**. Therefore, positional alignment of substrate **123** is accomplished and substrate **123** is ready for printing process in step **407**. Relative angle θ is determined by the following equation:

$$\theta = \cos^{-1}\left(\frac{l^2 + l^2 - z^2}{2ll}\right)$$

where l is the half distance of L (or L' since L'=L), i.e. distance between the intersecting point P and the first registration hole or second registration hole of screen mask **111** (or substrate **123**). l is a predetermined value that can be calculated with the equation $\sqrt{a^2+b^2}/2$, where a is the distance between the first and second registration holes of screen mask **111** (or substrate **123**) along the Y axis, and b is the distance between the first and second registration holes of screen mask **111** (or substrate **123**) along the X axis. z is the distance between the center point of the first (or second) circular registration hole of screen mask **111** and the center point of the first (or second) circular registration hole of substrate **123**. See FIG. **6**. The value of z can be calculated with the equation

$$\sqrt{X1'^2+Y1'^2} (\text{or } \sqrt{X2'^2+Y2'^2}).$$

At step **406**, the position of substrate **123** is corrected based on the calculated alignment values in step **405**. Substrate **123** is arranged to move laterally along the X axis by the calculated X_alignment and move laterally along the Y axis by the calculated Y_alignment. These movements ensure that the offsets in X and Y axes between the first registration holes **115**A, **125**A are same as the offsets in X and Y axes between the second registration holes **115**B, **125**B. After that, substrate **123** is arranged to rotate around an axis perpendicular to X-Y plane by the calculated relative angle θ. As such, substrate **123** will be vertically aligned with screen mask **111**.

At the stage where substrate **123** is perfectly aligned with screen mask **111**, screen printing process on substrate **123** will begin in step **407**. An optional step may be implemented between step **406** and **407** to check if the positional alignment of substrate **123** is successful. In this optional step, images of the registration holes will be captured similar to step **402** and determined whether substrate **123** is perfectly aligned with screen mask **111** before proceeding to screen printing process in step **407**. If substrate **123** is not properly aligned with screen mask **111**, alignment process may be activated and steps **405** and **406** are repeated.

While preferred embodiments of the present invention have been described and illustrated above, it is to be understood that they are exemplary of the invention and are not to be considered to be limiting. It is expected that those skilled in the art can and will design alternative embodiments that infringe this invention as set forth in the following claims.

What is claimed is:

1. A method for aligning a substrate with a screen mask in a screen printing system, the method comprising:

providing a screen mask (**111**) having first and second registration holes (**115**A, **115**B) through the screen mask (**111**);

positioning a substrate (**123**) below and substantially parallel to the screen mask (**111**), the substrate (**123**) having first and second registration holes (**125**A, **125**B) through the substrate (**123**);

capturing a first image of the first registration holes (**115**A, **125**A) of the screen mask (**111**) and the substrate (**123**) with a first image capturing device (**131**), wherein the first image shows the first registration hole (**115**A) of the screen mask (**111**) superimposed with the first registration hole (**125**A) of the substrate (**123**);

capturing a second image of the second registration holes (**115**B, **125**B) of the screen mask (**111**) and the substrate (**123**) with a second image capturing device (**132**), wherein the second image shows the second registration hole (**115**B) of the screen mask (**111**) superimposed with the second registration hole (**125**B) of the substrate (**123**);

determining from the first and second images whether the first and second registration holes (**125**A, **125**B) of the substrate (**123**) are vertically aligned with the first and second registration holes (**115**A, **115**B) of the screen mask (**111**) respectively;

calculating offsets between the first registration holes (**115**A, **125**A) from the first image and offsets between the second registration holes (**115**B, **125**B) from the second image in response to a determination that at least one of the registration holes (**125**A, **125**B) of the substrate (**123**) is not vertically aligned with the respective registration hole (**115**A, **115**B) of the screen mask (**111**);

calculating alignment values for correcting position of the substrate (**123**) based on the calculated offsets; and

correcting position of the substrate (**123**) based on the calculated alignment values so that the substrate (**123**) is vertically aligned with the screen mask (**111**).

2. The method of claim **1** wherein the step of calculating the offsets comprises:

measuring differences in distance between the first registration hole (**115**A) of the screen mask (**111**) and the first registration hole (**125**A) of the substrate (**123**) in a X axis and a Y axis orthogonal to the X axis wherein the X and Y axes define a horizontal X-Y plane parallel to the screen mask (**111**) and the substrate (**123**); and

measuring differences in distance between the second registration hole (**115**B) of the screen mask (**111**) and the second registration hole (**125**B) of the substrate (**123**) in the X axis and the Y axis.

3. The method of claim **2**, wherein the step of calculating the alignment values comprises:

modifying the calculated offsets so that the differences in the X axis and the Y axis between the first registration hole (**115**A) of the screen mask (**111**) and the first registration hole (**125**A) of the substrate (**123**) are the same as the differences in the X axis and the Y axis between the second registration hole (**115**B) of the screen mask (**111**) and the second registration hole (**125**B) of the substrate (**123**) respectively.

4. The method of claim 3, wherein the step of modifying the calculated offsets comprises:

calculating an X_alignment value by this equation: (X1+X2)/2, wherein X1 is the measured difference in the X axis between the first registration holes (115A, 125A) of the screen mask (111) and the substrate (123) and X2 is the measured difference in the X axis between the second registration holes (115B, 125B) of the screen mask (111) and the substrate (123); and

calculating a Y_alignment value by this equation: (Y1+Y2)/2, wherein Y1 is the measured difference in the Y axis between the first registration holes (115A, 125A) of the screen mask (111) and the substrate (123) and Y2 is the measured difference in the Y axis between the second registration holes (115B, 125B) of the screen mask (111) and the substrate (123).

5. The method of claim 4 wherein the step of calculating the alignment values further comprises:

calculating a relative angle between two intersecting line segments (L, L') based on the X_alignment value, the Y_alignment value and the calculated offsets wherein a first one of the intersecting line segments is linearly connecting the first and second registration holes (115A, 115B) of the screen mask (111) and a second one of the intersecting line segments is linearly connecting the first and second registration holes (125A, 125B) of the substrate (123).

6. The method of claim 5 wherein the relative angle is calculated using a trigonometry formula.

7. The method of claim 4 wherein the step of correcting position of the substrate (123) comprises:

moving the substrate (123) laterally along the X axis by the X_alignment value.

8. The method of claim 4 wherein the step of correcting position of the substrate (123) comprises:

moving the substrate (123) laterally along the Y axis by the Y_alignment value.

9. The method of claim 5 wherein the step of correcting position of the substrate (123) comprises:

rotating the substrate (123) by the relative angle around an axis perpendicular to the X-Y plane wherein the perpendicular axis is at an intersecting point of the two intersecting line segments (L, L').

10. The method of claim 9 wherein the intersecting point is a middle point between the first and second registration holes (115A, 115B) of the screen mask (111) and a middle point between the first and second registration holes (125A, 125B) of the substrate (123).

11. The method of claim 1 wherein the first and second registration holes (115A, 115B) of the screen mask (111) are being formed at opposite diagonal corner regions of the screen mask (111).

12. The method of claim 1 wherein the first and second registration holes (125A, 125B) of the substrate (123) are being formed at opposite diagonal corner regions of the substrate (123).

13. The method of claim 1 wherein the substrate (123) is a low temperature co-fired ceramic tape.

14. A system (100) for screen printing with alignment of a substrate with a screen mask, the system (100) comprising:

a screen mask holder (113) for holding a screen mask (111), the screen mask (111) having first and second registration holes (115A, 115B) through the screen mask (111);

a substrate holder (119) for receiving a substrate (123), the substrate (123) having first and second registration holes (125A, 125B) through the substrate (123);

first and second image capturing devices (131, 132);

an alignment system having a processing unit and a memory readable by the processing unit; and

instructions stored by the memory that direct the processing unit to:

position the substrate holder (119) below the screen mask holder (113) so that the substrate (123) is substantially parallel to the screen mask (111);

capture a first image of the first registration holes (115A, 125A) of the screen mask (111) and the substrate (123) with the first image capturing device (131), wherein the first image shows the first registration hole (115A) of the screen mask (111) superimposed with the first registration hole (125A) of the substrate (123);

capture a second image of the second registration holes (115B, 125B) of the screen mask (111) and the substrate (123) with the second image capturing device (132), wherein the second image shows the second registration hole (115B) of the screen mask (111) superimposed with the second registration hole (125B) of the substrate (123);

determine from the first and second images whether the first and second registration holes (125A, 125B) of the substrate (123) are vertically aligned with the first and second registration holes (115A, 115B) of the screen mask (111) respectively;

calculate offsets between the first registration holes (115A, 125A) from the first image and offsets between the second registration holes (115B, 125B) from the second image in response to a determination that at least one of the registration holes (125A, 125B) of the substrate (123) is not vertically aligned with the respective registration hole (115A, 115B) of the screen mask (111);

calculate alignment values for correcting position of the substrate (123) based on the calculated offsets; and

correct position of the substrate (123) based on the calculated alignment values so that the substrate (123) is vertically aligned with the screen mask (111).

15. The system of claim 14 wherein the substrate holder (119) is movable laterally along a first axis relative to the screen mask (111).

16. The system of claim 15 wherein the substrate holder (119) is movable laterally along a second axis orthogonal to the first axis relative to the screen mask (111).

17. The system of claim 14 wherein the substrate holder (119) is rotatable around an axis perpendicular to the screen mask (111).

18. The system of claim 14 wherein the screen mask holder (113) is movable vertically relative to the substrate holder (119).

19. The system of claim 14 further comprising:

a slidable table (121) on which the substrate holder (119) is mountable wherein the slidable table (121) is movable laterally relative to the screen mask holder (113).

20. The system of claim 14 further comprising:

an interface unit (107) in communication with the alignment system wherein the interface unit (107) allows a user to view images and/or enter data.

21. The system of claim 14 wherein the first and second registration holes (115A, 115B) of the screen mask (111) are being formed at opposite diagonal corner regions of the screen mask (111).

22. The system of claim 14 wherein the first and second registration holes (125A, 125B) of the substrate (123) are being formed at opposite diagonal corner regions of the substrate (123).

23. The system of claim 14 wherein the substrate (123) is a low temperature co-fired ceramic tape.

24. The system of claim 14 wherein the instructions to calculate the offsets comprise:

instructions to measure differences in distance between the first registration hole (115A) of the screen mask (111) and the first registration hole (125A) of the substrate (123) in a X axis and a Y axis orthogonal to the X axis wherein the X and Y axes define a horizontal X-Y plane parallel to the screen mask (111) and the substrate (123); and

instructions to measure differences in distance between the second registration hole (115B) of the screen mask (111) and the second registration hole (125B) of the substrate (123) in the X axis and the Y axis.

25. The system of claim 24 wherein the instructions to calculate the alignment values comprise:

instructions to modify the calculated offsets so that the differences in the X axis and the Y axis between the first registration hole (115A) of the screen mask (111) and the first registration hole (125A) of the substrate (123) are same as the differences in the X axis and the Y axis between the second registration hole (115B) of the screen mask (111) and the second registration hole (125B) of the substrate (123) respectively.

26. The system of claim 25 wherein the instructions to modify the calculated offsets comprise:

instructions to calculate a X_alignment value by this equation: (X1+X2)/2 wherein X1 is the measured difference in the X axis between the first registration holes (115A, 125A) of the screen mask (111) and the substrate (123) and X2 is the measured difference in the X axis between the second registration holes (115B, 125B) of the screen mask (111) and the substrate (123); and

instructions to calculate a Y_alignment value by this equation: (Y1+Y2)/2 wherein Y1 is the measured difference in the Y axis between the first registration holes (115A, 125A) of the screen mask (111) and the substrate (123) and Y2 is the measured difference in the Y axis between the second registration holes (115B, 125B) of the screen mask (111) and the substrate (123).

27. The system of claim 26, wherein the instructions to calculate the alignment values further comprise:

instructions to calculate a relative angle between two intersecting line segments (L, L') based on the X_alignment value, the Y_alignment value, and the calculated offsets wherein a first one of the intersecting line segments is linearly connecting the first and second registration holes (115A, 115B) of the screen mask (111) and a second one of the intersecting line segments is linearly connecting the first and second registration holes (125A, 125B) of the substrate (123).

28. The system of claim 27, wherein the relative angle is calculated using a trigonometry formula.

29. The system of claim 26, wherein the instructions to correct position of the substrate (123) comprise:

instructions to move the substrate (123) laterally along the X axis by the X_alignment value.

30. The system of claim 26, wherein the instructions to correct position of the substrate (123) comprise:

instructions to move the substrate (123) laterally along the Y axis by the Y_alignment value.

31. The system of claim 27, wherein the instructions to correct position of the substrate (123) comprise:

instructions to rotate the substrate (123) by the relative angle around an axis perpendicular to the X-Y plane wherein the perpendicular axis is at an intersecting point of the two intersecting line segments (L, L').

32. The system of claim 31 wherein the intersecting point is a middle point between the first and second registration holes (115A, 115B) of the screen mask (111) and a middle point between the first and second registration holes (125A, 125B) of the substrate (123).

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,421,755 B2
APPLICATION NO. : 14/210964
DATED : August 23, 2016
INVENTOR(S) : Muhammad Redzuan bin Saad et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title Page

Page 1, insert item 30 priority to -- Malaysian Patent Application No. PI 2013700424 --

Signed and Sealed this
Twenty-fifth Day of October, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office